

# Development of Silicon-substrate Based Fabry-Perot Etalons for far-IR Astrophysics

Completed Technology Project (2016 - 2018)



## Project Introduction

We propose to design, construct and test silicon-substrate-based (SSB) mirrors necessary for high performance Fabry-Perot interferometers (FPIs) to be used in the 25-40  $\mu\text{m}$  mid-IR band. These mirrors will be fabricated from silicon wafers that are anti-reflection coated (ARC) by micromachining an artificial dielectric meta-material on one side, and depositing optimized gold-metalized patterns on the other. Two mirrors with the metalized surfaces facing one-another form the Fabry-Perot cavity, also known as the FPI etalon. The exterior surfaces of the silicon mirrors are anti-reflection coated for both good transmission in the science band, and to prevent unwanted parasitic FPI cavities from forming between the four surfaces (one anti-reflection coated, one metalized for each mirror) of the FPI etalon. The mirrors will be tested within a Miniature Cryogenic Scanning Fabry-Perot (MCSF) that we have designed through support of a previous NASA grant (NNX09AB95G). This design is based on our long experience in constructing and using scanning FPI in the mid-IR to submm range, and fits within test-beds we have on hand that are suitable for both warm and cold tests. The key technologies are the ARC and tuned mirrors that are enabled by silicon nano-machining techniques. The creation of these SSB mirrors promises greatly improved performance over previous versions of mid-IR to submm-band FPIs that are based on mirrors made from free-standing metal mesh stretched over support rings. Performance is improved both structurally and in terms of sensitivity, and is measured as the product of the cavity finesse times transmission. Our electromagnetic modeling suggests that SSB mirrors will improve this product by a factor of 2 over the best free standing mesh etalons available. This translates into a factor of  $\sqrt{2}$  improvement in sensitivity per etalon, or a full factor of 2 when used in a tandem (dual etalon) FPI spectrometer. The SSB improvements are due to both the stiff ( $\sim 0.8$  mm thick) silicon substrate and the silicon nanofabrication techniques and include the effects of (1) precisely tuned reflective surfaces, (2) very smooth mirror surfaces leading to greater cavity efficiency, (3) reduced susceptibility to vibrations due the silicon support structures, (4) reduced susceptibility to defect finesse due to reduced mounting stress, and (5) greatly improved mechanical robustness that could result in space-qualified hardware. These improvements are enabled by the combination of silicon-based technologies and our sophisticated electromagnetic modeling. The finished products have many science applications. For example, the SSB mirrors within an MCSF would convert the FORCAST or HAWC+ cameras on SOFIA into imaging spectrometers capable of widescale mapping of the mid to far-IR fine structure lines from the Galactic Center, Galactic star formation regions and external galaxies. In fact, this new etalon technology could be used in any mid to far-IR camera, converting the camera into a moderate (100 to 4000) to high resolving power ( $\sim 100,000$ ) imaging spectrometer at modest cost. A particularly interesting application could be a large format ( $\sim 10$  cm diameter) FPI that could deliver resolving powers in excess of 5000 for a 10 m space telescope, which might be the incarnation of the next major far-IR space mission (see NASA Cosmic Origins



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## Organizational Responsibility

### Responsible Mission Directorate:

Science Mission Directorate (SMD)

### Responsible Program:

Astrophysics Research and Analysis

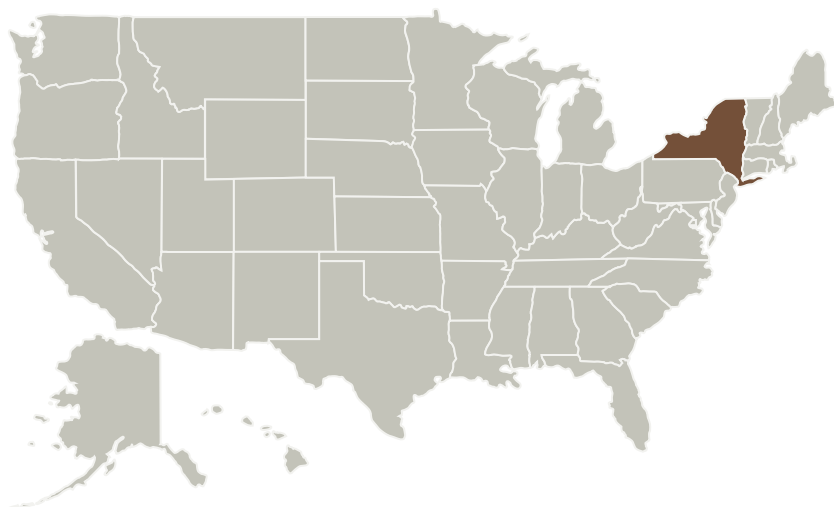
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Newsletter, V4, No. 1, March 2015). Our program addresses NASA's Strategic goal 1: "Expand the frontiers of knowledge, capability, and opportunity in space."; Objective 1.6: "Discover how the Universe works, explore how it began and evolved, and search for life on planets around other stars," specifically "Technology development and demonstration." It also addresses Strategic Goal 2 via Objective 2.4: "Advance the Nation's STEM education and workforce pipeline by working collaborative with other agencies to engage students, teachers, and faculty in NASA's missions and unique assets."

## Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Cornell University	Supporting Organization	Academia	Ithaca, New York

## Primary U.S. Work Locations

New York

## Project Management

### Program Director:

Michael A Garcia

### Program Manager:

Dominic J Benford

### Principal Investigator:

Gordon J Stacey

### Co-Investigators:

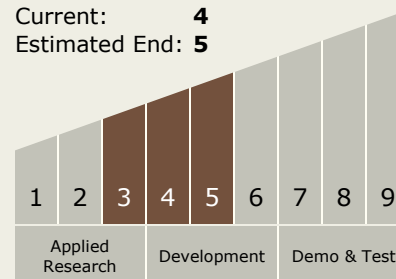
German Cortes-medellin

Thomas Nikola

Brenda M Truesdail

## Technology Maturity (TRL)

Start: 3  
Current: 4  
Estimated End: 5



## Technology Areas

### Primary:

- TX08 Sensors and Instruments
  - TX08.2 Observatories
    - TX08.2.1 Mirror Systems

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## Target Destination

Outside the Solar System